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Naval Facilities Engineering Command
NAVFAC HAWAII

Simplified 3D LNAPL Modeling Parameters

Red Hill Bulk Fuel Storage Facility
May 17, 2019

Introduction

- Meeting Objectives
  - Develop consensus on parameters and parameter bounds to support simplified 3D LNAPL modeling
  - Develop consensus on model calibration

Current Status of Evaluation of LNAPL Modeling Approach

- AOC agreements
- Deliverables extension – applicability to LNAPL modeling
- Navy evaluating the possibility of conducting this additional type of modeling

Model Limitations and Use of Model

- Based on equivalent porous media approach and is a simplification of reality
  - Requires use of a reasonable range of values for key parameters
- Provides a general understanding of potential risk to receptors
- Provides a general understanding of how various size releases may behave
  - Extent of LNAPL
  - Timing of LNAPL
- Use for developing source terms as part of the CF&T model

Parameter Considerations for Modeling of LNAPL Release Scenarios

Model Parameterization

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LNAPL model parameter values

- Establish bounds for model parameters based on a range of reasonably conservative values considering:
  - Field observations
  - Appropriate literature values
  - Core analysis

Establishing Bounds

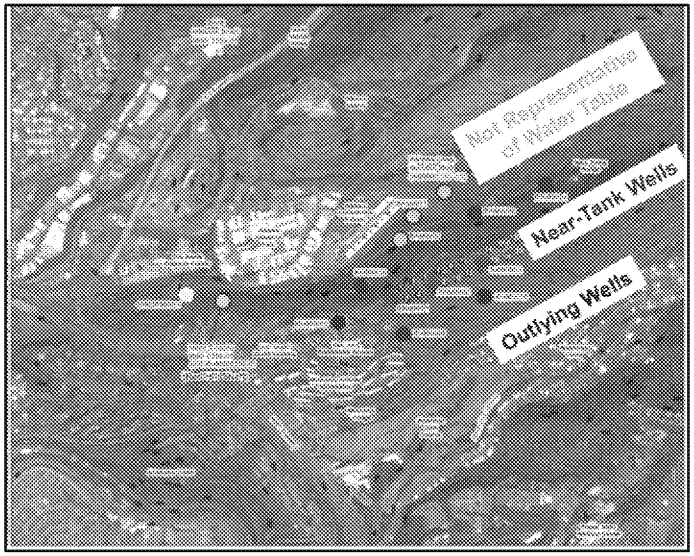
- LNAPL model must be consistent with observed geology
- LNAPL model must be consistent with understanding of impacts from Jan. 2014 release

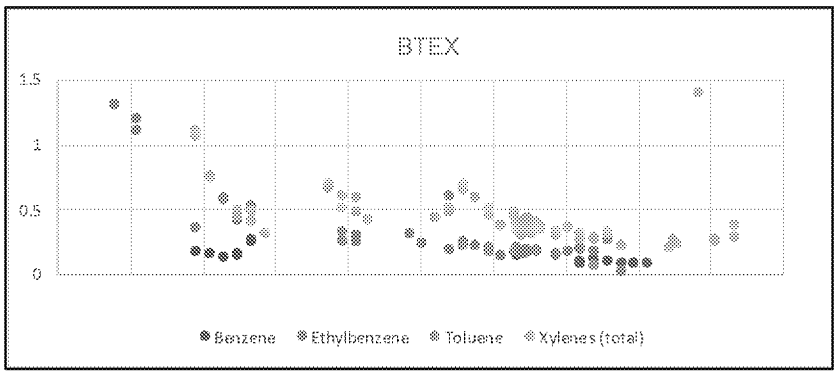
Approach:

- Define initial ranges for model parameters based on literature and site measurements
- Refine/constrain parameter values based on observations of Jan. 2014 release
  - Extent of LNAPL in vadose zone and groundwater
  - Extent of dissolved groundwater plume

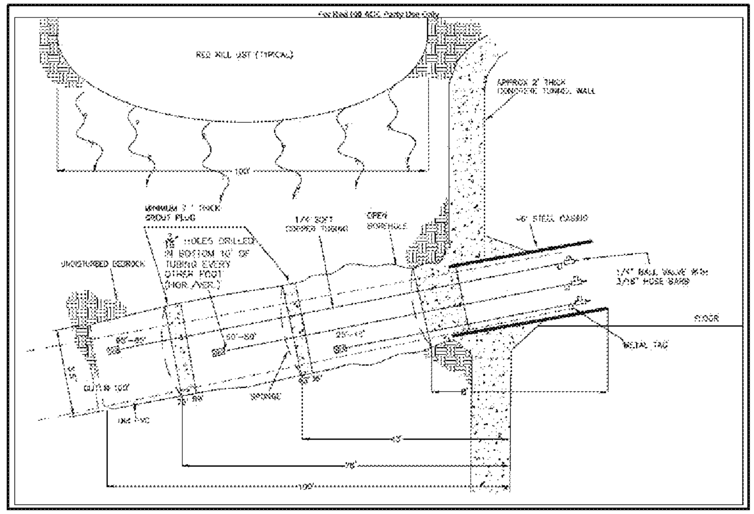
LNAPL Model Parameter Considerations - Examples of Field Observation Types

Groundwater Monitoring Wells





Soil Vapor Probes



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Key Concept

Simulate the 2014 release with eight model runs composed of:

- **four holding capacity models**

X

- **two hydrogeologic alternatives**

See which ones reasonably match the observed data

Approach

1. For each of the eight model runs, run model to simulate for 1 year.
2. Generate figures (cross-section and plan view) showing simulated LNAPL migration through unsaturated zone and along water table.
3. Classify runs into two buckets:
   - Consistent Bucket: Meets Consistency Criteria
   - Inconsistent Bucket : All others
4. Using Consistent runs, refine input parameters to bound.

Consistency Criteria: Groundwater Monitoring Results

Wells Used With Criterion
RHMW01
RHMW03
RHMW04
RHMW05
RHMW06
RHMW07
RHMW08
RHMW09
RHMW10
RHMW11-05
Red Hill Shaft

Method:

Step 1. Determine simulated LNAPL saturations at water table in model grid cell where each well is located.

Step 2. If simulated LNAPL saturation is zero in all of these cells, model run is "Consistent" with observed data.

Justification:

- No LNAPL was directly observed in any monitoring well after the Jan. 2014 release. (The potential observation in purge water from RHMW02 was prior to Jan 2014).
- There were no increases in dissolved phase concentration in any of these wells that are attributable to the Jan. 2014 release.

Consistency Criteria: Groundwater Monitoring Results

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Wells Used With Criterion

RHMW01
RHMW03
RHMW04
RHMW05
RHMW06
RHMW07
RHMW08
RHMW09
RHMW10
RHMW11-05
Red Hill Shaft

Method:

Step 1. Determine simulated LNAPL saturations at water table in model grid cell with well.

Step 2. If simulated LNAPL saturation is zero in all of these cells, model run is "Consistent"

Justification:

- No LNAPL was directly observed in any monitoring well after the Jan. 2014 release. (The potential observation in RHMW02 was prior to Jan 2014).
- There were no increases in dissolved-phase concentration in any of these wells that are attributable to the Jan. 2014 release.

Wells Excluded from Criterion

RHMW02
Halawa Deep

RHMW02 *not included as the AOC Parties disagree whether dissolved-phase concentrations are attributable to the Jan. 2014 release.*

Halawa Deep *is screened well below the water table.*

Consistency Criteria: Soil Vapor Monitoring Data

Soil Vapor Probes Used
Tank 2 Soil Vapor Probes
Tank 4 Soil Vapor Probes
Tank 6 Soil Vapor Probes
Tank 7 Soil Vapor Probes
Tank 8 Soil Vapor Probes
Tank 9 Soil Vapor Probes
Tank 10 Soil Vapor Probes
Tank 11 Soil Vapor Probes
Tank 12 Soil Vapor Probes
Tank 13 Soil Vapor Probes
Tank 14 Soil Vapor Probes
Tank 15 Soil Vapor Probes
Tank 16 Soil Vapor Probes
Tank 17 Soil Vapor Probes
Tank 18 Soil Vapor Probes
Tank 20 Soil Vapor Probes

Method:

Step 1. Determine the simulated LNAPL saturation in the cell or cells containing the three Tank 5 Soil Vapor probes (located approximately 20 to 40 feet below bottom of Tank 5) and use single value if all vapor probes are in one model cell, or the average of the LNAPL saturation if more than one model cell.

Step 2. Determine simulated LNAPL saturation in cells containing soil vapor probes in all tanks listed to left.

Step 3. If all of the Step 2 simulated LNAPL saturations are less than 25% of the Step 1 LNAPL saturation, then Model Run is "Consistent" with observed data.

Justification:

PID readings at the Tank 5 soil vapor monitoring wells spiked rapidly from less than 1,000 ppbv in December 2013 to greater than 200,000 ppbv in January 2014 corresponding to the 2014 Tank 5 release event. PID readings at Tank 5 peaked at 450,000 ppbv May 2014 and have then decreased over time consistent with biological weathering and other NSZD processes. In contrast, PID readings from below other tanks showed a much smaller increase, indicating that little or no LNAPL migrated laterally below these tanks within the depth interval of 20 to 40 ft below the tanks.

Consistency Criteria:
Soil Vapor Monitoring Data

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Soil Vapor Probes Used

Tank 2 Soil Vapor Probes
Tank 4 Soil Vapor Probes
Tank 6 Soil Vapor Probes
Tank 7 Soil Vapor Probes
Tank 8 Soil Vapor Probes
Tank 9 Soil Vapor Probes
Tank 10 Soil Vapor Probes
Tank 11 Soil Vapor Probes
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Tank 14 Soil Vapor Probes
Tank 15 Soil Vapor Probes
Tank 16 Soil Vapor Probes
Tank 17 Soil Vapor Probes
Tank 18 Soil Vapor Probes
Tank 20 Soil Vapor Probes

Method:

Step 1. Determine the simulated LNAPL saturation in the cell or cells containing the three Tank 5 Soil Vapor probes (located approximately 20 to 40 feet below bottom of Tank 5) and use single value if all vapor probes are in one model cell, or the average of the LNAPL saturation if more than one model cell.

Step 2. Determine simulated LNAPL saturation in cells containing soil vapor probes in all tanks listed to left.

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Justification:

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Soil Vapor Probes Excluded

Tank 3 Soil Vapor Probes
Tank 1 Soil Vapor Probes
Tank 19 Soil Vapor Probes

Tank 3: This location is likely unimpacted by LNAPL, despite a one-time elevated soil vapor reading on March 25, 2014. Confidence in the absence of LNAPL at this tank is lower than at other tanks.

Tank 1: No PID readings collected from these soil vapor probes.

Tank 19: No PID readings collected from these soil vapor probes.

Consistency Criteria: Need Both Criteria Satisfied for a Model Run to be "Consistent"

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Groundwater Monitoring Wells

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RHMW01
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RHMW05
RHMW06
RHMW07
RHMW08
RHMW09
RHMW10
RHMW11-05
Red Hill Shaft

Method:
Step 1. Determine simulated LNAPL saturations at water table in model grid cell with well.
Step 2. If simulated LNAPL saturation is zero in all of these cells, model run is "Consistent"

Justification:
- No LNAPL was directly observed in any monitoring well after the Jan. 2014 release. (The potential observation in RHMW02 was prior to Jan 2014).
- There were no increases in dissolved phase concentration in any of these wells that are attributable to the Jan. 2014 release.

Wells Excluded from Criterion
RHMW02
Halawa Deep

RHMW02 *not included as the AOC Parties disagree whether dissolved-phase concentrations are attributable to the Jan. 2014 release.*

H. Deep *is screened well below the water table.*

Soil Vapor Probes

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RHMW01
RHMW03
RHMW04
RHMW05
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Wells Excluded from Criterion
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CRITERIA SYNTHESIS: CONSISTENT OR INCONSISTENT?

If both criteria above are satisfied, then model run is **"Consistent"** with observed data.

If any criteria are not met, model run is **"Inconsistent"** with observed data.

LNAPL Model Parameters for the Eight Model Runs Simulating Jan. 2014 Release

GENERAL PARAMETER LIST	VALUE	VALUE	UNITS
LNAPL Properties			
Viscosity	1.234	*na*	centipoise
Density	0.807	*na*	g/mL
Media/water/air/LNAPL properties			
Interfacial Tension (water:LNAPL)	15.7	*na*	Dynes/centimeter
Surface Tension (LNAPL:air)	25	*na*	Dynes/centimeter
Surface Tension (water:air)	69.9	*na*	Dynes/centimeter
2-phase Air – NAPL (AN) relationship			
van Genuchten Alpha for air-water system	0.44	*na*	1/ft
van Genuchten Beta	2.68	*na*	(-)
Brooks Corey "n"	4.19	*na*	(-)
Scaled Alpha for LNAPL-water system	1.96	*na*	1/ft
Scaled Alpha for air-LNAPL system	1.23	*na*	1/ft
Basic Geologic Media Properties			
Net Porosity	*see below for Models*		
LNAPL Residual Saturation	*see below for Models*		
Occupied LNAPL Residual Saturation	*see below for Models*		
Dip of Basalt	2.9	*na*	Degrees
Dip Azimuth	214	*na*	Degrees
Horizontal Hydraulic Conductivity	*see below for Models*		
Vertical Hydraulic Conductivity	*see below for Models*		
Hydrologic Properties			
Slope of water table	0		ft/ft

From actual jet fuel sample from Red Hill

Carsel and Parrish (1988) values for sand

AOC Parties

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LNAPL Model Parameters for the Eight Model Runs Simulating Jan. 2014 Release

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ALL EIGHT MODELS

All Models			
Release Volume	27,000	27,000	gallons
Release Duration	34	34	days

LNAPL Model Parameters for LNAPL Model 1: Literature Data

Model 1: Literature Data	Sub-Models		
	1a	1b	
Net Porosity	7.5	7.5	%
LNAPL Residual Saturation*	6	6	*% of Net Porosity
Calc. Inverse Specific Retention (ISR)	30	30	ft3 basalt/gal LNAPL
Kx	*5000*	*500*	*ft/day*
Kx/Kz	*100*	*10*	*(-)*
Kz	*50*	*50*	*ft/day*

Data Source

Average of typical specific yield from Nichols, Shade, Hunt (1996)
Avg of lab values for coarse gravel, Brady and Kunkel (2005). Water specific retention assumed to be low.
Calculated
Bounding range of Kx for basalt
Depending on simulation, these may be altered to match 2014 release conceptual model

ISR of 30: Cubic feet of basalt volume needed to hold 1 gallon LNAPL
Equal to 1 gallon of jet fuel in rear trunk space in Ford Escape
(0.4% of aquifer filled with LNAPL)

LNAPL Model Parameters for LNAPL Model 2: Core Labs Data

Model 2: Core Labs Data

	Sub-Models		
	2a	2b	
Net Porosity	25	25	%
LNAPL Residual Saturation*	40	40	*% of Net Porosity
Calc. Inverse Specific Retention (ISR)	1.3	1.3	ft3 basalt/gal LNAPL
Kx	*5000*	*500*	*ft/day*
Kx/Kz	*100*	*10*	*(-)*
Kz	*50*	*50*	*ft/day*

Data Source

Core Labs measurements of porosity of Pahoehoe from Red Hill sample x 9/11 to convert to Net Porosity.
Core Labs measurements of Res. Sat. of Pahoehoe from Red Hill samples. Water sp. ret. assumed low.
Calculated
Bounding range of Kx for basalt
Depending on simulation, these may be altered to match 2014 release conceptual model

ISR of 1.3: Cubic feet of basalt volume needed to hold 1 gallon LNAPL.
Equal to 1 gallon jet fuel in 10-gallon ice chest
(10% of aquifer filled with LNAPL)

LNAPL Model Parameters for LNAPL Model 3: Navy Holding Capacity Calculation

Model 3: "Contained in Volume" 27,000 Gallon 2014 Release (Navy Interpretation)

	Sub-Models		
	3a	3b	
Net Porosity	7.5	7.5	%
LNAPL Residual Saturation*	2.7%	2.7%	*% of Net Porosity
Calc. Inverse Specific Retention (ISR)	67	67	ft3 basalt/gal LNAPL
Kx	*5000*	*500*	*ft/day*
Kx/Kz	*100*	*10*	*(-)*
Kz	*50*	*50*	*ft/day*

Data Source

Average of typical specific yield from Nichols, Shade, Hunt (1996)
Calculated
Upper limit value assuming LNAPL retained in 200 ft x 200 ft x 45 ft zone underlying and near Tank 5.
Bounding range of Kx for basalt
Depending on simulation, these may be altered to match 2014 release conceptual model

ISR of 67: Cubic feet of basalt volume needed to hold 1 gallon LNAPL
Equal to 1 gallon of jet fuel in Ford Expedition storage 3rd row seats up.
(0.2% of aquifer filled with LNAPL)

LNAPL Model Parameters for LNAPL Model 4: Alternative Holding Capacity Calculation

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Model 4: "Contained in Volume" 27,000 Gallon 2014 Release (Alternative Interpretation)

	Sub-Models		
	4a	4b	
Net Porosity	7.5	7.5	%
LNAPL Residual Saturation*	0.13%	0.13%	*% of Net Porosity
Calc. Inverse Specific Retention (ISR)	1400	1400	ft3 basalt/gal LNAPL
Kx	*5000*	*500*	*ft/day*
Kx/Kz	*100*	*10*	*(-)*
Kz	*50*	*50*	*ft/day*

Data Source

Average of typical specific yield from Nichols, Shade, Hunt (1996)

Assumes LNAPL was retained in eq six tank volume: 600 ft x 600 ft x 105 ft zone down to water table.

Calculated

Bounding range of Kx for basalt

Depending on simulation, these may be altered to match 2014 release conceptual model

ISR of 1400: Cubic feet of basalt volume needed to hold 1 gallon LNAPL
Equal to 1 gallon of jet fuel in half-full truck trailer.
(0.010% of aquifer filled with LNAPL)

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Key Concept Summary

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Simulate the 2014 release with eight model runs composed of:

- **four holding capacity models**

X

- **two hydrogeologic alternatives**

See which ones reasonably match the observed data

AOC Parties Feedback

Path Forward

Summary of Key Issues / Action Items